Combining Forest-level Analysis with Options Valuation Approach-A New Framework for Assessing Forestry Investment

Runsheng Yin

ABSTRACT. The conventional forest investment assessment at the stand level has difficulty dealing with multiple decisions and capturing the operational flexibility involved in timber production. By combining forest-level analysis with the options valuation approach, this article suggests a new framework for forestry investment assessment. We first articulate the new framework and discuss a few technical issues encountered in adopting it. Then, we present three empirical examples (entry decision, land acquisition, and harvest timing) to illustrate how forest-level analysis and/or real options valuation can be done and what we may learn from this type of exercise. We believe that while adopting this new framework entails challenges, it represents a great opportunity to expand the field of forest investment assessment. FOR. SCI. 47(4):475–483.

Key Words: Faustmann model, profit function, operation decisions, market uncertainty and risk, stochastic price processes, landowner behavior.

WHEN TO CUT A STAND OF TREES has remained the central question in forest investment assessment ever since Faustmann (1849). And in the last quarter of the 20th century, the research focus has shifted from deterministic to stochastic analysis. Since Norström's work, *'A Stochastic Model for the Growth Period Decision in Forestry,"* appeared in 1975, many articles have been published on the subject of timber rotation determination in an environment of uncertain market price and/or tree growth. Although somehow related, different studies feature different tree-cutting rules. Lohmander (1987), Brazee and Mendelsohn (1988), Haight (1990), and others derive the reservation price rule; Clarke and Reed (1989) and Reed and Clarke (1990) formulate the myopic stopping rule; and Thompson (1992) and Plantinga (I 998) obtain the option value rule. This body of work has undoubtedly expanded the scope of forest investment assessment and improved our understanding of the effect of risk and uncertainty on harvest timing and its benefit.

However, a common problem of the previous studies is that almost all of them are oriented toward rotation determination at the stand level, even though forest investment involves far more than the harvest decision itself. At the stand level, harvest and regeneration decisions are made intermittently, and the regeneration decision is subsequent to the harvesting decision, whereas at the forest-level harvest, regeneration and other activities are conducted continuously. Obviously, the focus of a stand-level analysis should and could only be optimal stopping. As a result, while the harvest decision has received disproportionate attention, other decisions have largely been ignored.

To our knowledge, Bumes et al. (1999) and Yin and Newman (1996, 1999) are the only studies examining forest-level operation decisions under uncertainty. Burnes et al. (1999) formulate a quantitative framework for offering tim-

Runsheng Yin, Department of Forestry, College of Agriculture and Natural Resources, Michigan State University, East Lansing, MI 48824—Phone: (517) 432.3352; Fax: (517) 432-1143; E-mail: yinr@msu.edu.

Acknowledgments: The author expresses his thanks to Dick Brazee, Jan Caulfield, Joe Chang, David Newman, Peichen Gong, and other participants of the 1999 Faustmann Symposium for their comments. He is also grateful for the review assistance by the three anonymous referees and journal editors. Financial support for the author's early work was provided by USDA Forest Service Economics of Forest Protection and Management Unit.

Manuscript received January 28, 2000. Accepted March 15. 2001.

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ber harvest bids on federal lands, which includes special considerations of the volatility of timber indices and the harvest costs. Yin and Newman (I 996) deal with the effect of catastrophic risk on the entry decision, whereas Yin and Newman (I 999) address the impact of market risk on entry, exit, mothballing, and reactivation decisions. These studies show that by modeling at the forest level, forestry management becomes continuous, so that the door is opened for exploring multiple operation decisions. As such, these authors have been able to apply the recent developments in capital budgeting-real options valuation-to analyze various forest investment options and shed new light on some important forestry issues.

Speaking of real options valuation, progress in the last 15 yr has greatly enhanced capital budgeting (Brennan and Schwartz 1985, McDonald and Siegel 1985, Dixit and Pindyck 1994, p. 135-425). Now it is held that the basic inadequacy of the net present value (NPV) and other discounted cash flow approaches to capital budgeting is that they ignore, or cannot properly capture, an investor's flexibility to adapt and revise later decisions. In particular, the NPV approach makes implicit assumptions concerning an "expected scenario" of cash flows and presumes an investor's commitment to a certain "operating strategy." Typically, an expected pattern of cash flows over a prespecified project life is discounted at a risk-adjusted interest rate to obtain the project's NPV. An immediate decision is then made to accept any project with a positive NPV.

In the real world of uncertainty, however, the realization of cash flows will probably differ from what an investor originally expected. As new information arrives and uncertainty about future cash flows unfolds, the investor may find that various projects allow varying degrees of flexibility to depart from and revise the operating strategy he or she originally anticipated. The importance of this flexibility is furtherhighlighted given that investment expenditures can be irreversible. That is, once a decision is made, the associated financial outlay becomes more or less a sunk cost, which can't be fully recovered. Indeed, it is the presence of irreversibility that makes it more valuable to wait for new information, and it is the combined effect ofuncertainty and irreversibility that deems the critical values at which various decisions are made different from those in a deterministic world (McDonald and Siegel 1985, Pindyck 1991, Dixit 1992). Therefore, an investor's flexibility to adapt his future actions in response to the changed environment introduces an asymmetric probability distribution of NPV, which expands the investment opportunity's true value by improving its upside potential while limiting its downside losses relative to the investor's initial static expectations. As suggested by Trigeorgis (I 996, p. 12 l-l 24), this asymmetry calls for an expanded NPV criterion that reflects both components of an investment opportunity's value: the static NPV of directly measurable expected cash flows and an option premium capturing the value of operating flexibility.

As mentioned, a few forest economists have already applied the options valuation techniques (Thompson 1992, Plantinga 1998). Moreover, many have recognized the relevance of decision flexibility in forestry due to its biological nature and have understood the need for adaptive management (e.g., Gong 1998, Reed and Haight 1996, Albers 1996, and Binkley 1993). Unfortunately, confining to the stand-level analysis only allows us to treat harvest as a call option, with the flexibility and adaptability found in other aspects oftimber production not being captured.[1] It is based on these considerations that Yin and Newman (I 996, 1999) advocate for the adoption of the forest-level analysis and the options valuation approach.

Therefore, the primary objective of this article is to propose a new framework for forest investment assessment under market uncertainty, which features the evaluation of real investment options at the forest level. To that end, we will articulate the forest-level analytic framework and forestry investment options in the next section. In section 3, we will address some technical issues involved in adopting the proposed framework. Then, in section 4, we will present three empirical examples to illustrate its potential applications. A few closing remarks follow in the fifth section.

A New Framework

Modeling at the Forest Level

Forest investment has been usually analyzed with the Faustmann model (Faustmann 1849, Samuelson 1976). As originally discussed in Conrad and Clark (I 987, p. 76–80) and Comolli (1980) and later reviewed by Yin and Newman (1997), two shortcomings of this model are the point-input/point-output feature and blurring of contributions from capital and land. The former implies a pulse process in which trees are planted now and harvested in certain years, and then replanted and harvested again in certain years. This treatment conceals the continuous nature of timber production. The blurring of contributions from capital and land results from the stand-level formulation itself, where capital cost is embedded in discounting future harvest revenues, and land cost is encompassed in the so-called "land expectation value" term. This practice makes it difficult, if not impossible, to allocate these factors efficiently and analyze them effectively.

Using Smith (I 961, p. 1 O-85) and Samuelson's (1976) ideas, Comolli (I 980) transformed the stand- level Faustmann formulation into a forest-level profit function. With further modifications by Yin and Newman (I 997), this profit function takes the form of

$$\pi(t) = P_t F(t) - i_t P_t I(t) - W_t K(t) - R_t L(t) \qquad (1)$$

According to this formulation, a producer incurs an initial outlay of M dollars at time t = 0 in establishing forest inventory I(t); thereafter, facing market price P_t, unit operating cost W_t, land rental cost R_t, and an interest rate of i_t, he produces a flow of outputs $F(t)$ into the future as operating inputs K(t) and land acreage $L(t)$ are committed. To some, the instantaneous relationship between the inputs and output may seem unrealistic. However, at the forest level, the time

[1] We will define put and call options and explain why the harvest decision is a call option later. But it is worth noting that Plantinga (I 998) refers to the harvest decision as a put option.

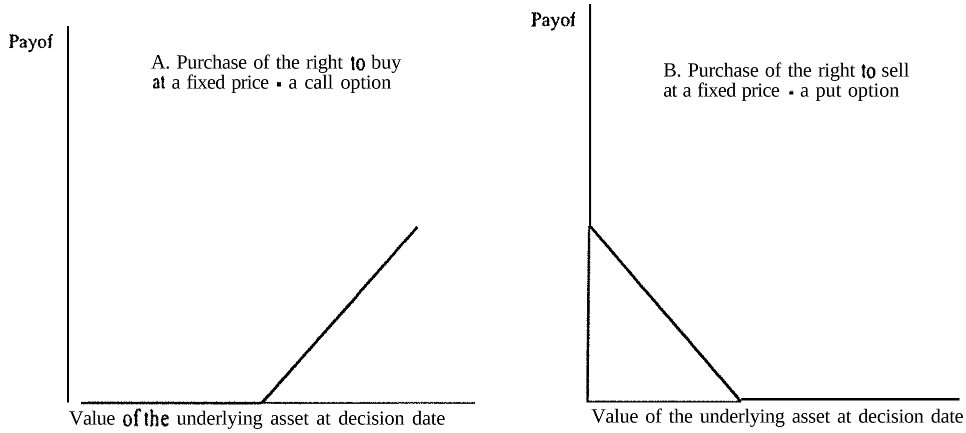

Figure 1. An illustration of the payoffs of put and call options.

lag between inputs and output is no longer a major problem. First, this is because every segment of the forest warrants operating inputs and land occupation prior to harvest. Second, inputs used in the past have been transformed into capital in the form of inventory.*

The above formulation views timber production as a continuous process and explicitly reveals various input and output dimensions. Nonetheless, it may be suspected or even objected to on the grounds that a majority of individual NIPF owners hold small pieces of timberland, and their harvesting is infrequent. As such, it would be more appropriate to assess their enterprises at the stand level. However, this argument lacks merit if we examine the roles different private landowners play in timber production more closely. Among private landowners, industrial and institutional as well as NIPF landowners who hold large tracts, though small in number, provide the bulk of timber production in the United States. Birch (1994) reports that, while more than 90% of the private owners have fewer than 100 ac of forestland each, together they control only 30% of the private forestland. Clearly, the decisions of owners of large tracts go beyond the harvest of a single timber stand. In other words, even if the continuous operations model is inappropriate for landowners with small holdings, there is a need to look at such a model given that most land is owned by landowners with large holdings. Caulfield and Newman (1999) observe that the stand-level risk and uncertainty analysis is of little relevance to institutional landowners because they rarely make decisions stand by stand. We tend to believe that this also holds for industrial landowners. Indeed, it can be argued that even for small NIPF holders, if our interest is not limited to the evaluation of individual investments, then the stand-level analysis may be inadequate. This is because understanding of the production behavior of these small holders as a group requires us to look into various aspects of their activities.

In retrospect, it seems that in addition to the Faustmann tradition, the stand-level, rotation-oriented forest investment assessment has to do with the historic development of forestry. We know that forestry originated from and, in certain regions, remains to be drawing down natural forests. Therefore, it was legitimate to focus on determining the rotation of a timber stand. However, that situation has changed as more and more intensive management practices are adopted to enhance forest productivity. When more human inputs are used in production, it becomes more necessary to examine every dimension of forestry.

Forest Investment Options

Traditional discounted cash flow techniques cannot properly capture the operating flexibility and strategic aspects of a project. Nevertheless, we can assess these crucial aspects by thinkingofinvestmentopportunities ascollectionsofoptions on real assets through the option-based techniques of contingent-claim analysis. An option is a contract that gives its holder the right to buy or sell an underlying asset at a fixed price. There are two types of options: put and call (Hull 1997, p. 4-5). A call option on an asset gives its owner the right to buy the asset by paying a preset price (the exercise price). A put option gives its owner the right to sell the asset at a preset price. An option contract is flexible: its holder is not obligated to purchase or sell anything. Thus, to exercise an option is to exercise the right to buy or sell the underlying assets. As shown in Figure 1, put and call options feature different payoffstructures. A call option is executed only if the market price of the asset exceeds the exercise price, whereas a put option is executed only if the market price of the asset falls below the exercise price. Options come in two basic styles with regard to exercise rights: American and European. American options may be exercised at any time during the life of the option contract, while European options may only be exercised at expiration.

Just as an owner of an American call option on a financial asset has the right-but not the obligation-to acquire the asset by paying a fixed price on or before a predetermined expiration date, and will exercise the option when it is in his or her best interest to do so (Chance 1998, p. 28–58), so will the holder of an option on real assets. That is, the owner of a discretionary investment opportunity has the right-but not the obligation-to acquire the (gross) present value of ex-

2 For a more detailed discussion on related issues, including a characterization of the production technology associated with this formulation. see Yin and Newman (I 997).

pected cash flows by making an investment outlay on or before the anticipated date when the investment opportunity will cease to exist. Just like the owner of the American call knows the current value of the stock but is uncertain about the future value of it, the holder of a real option knows the present value of expected cash flows of the investment project but is uncertain about the future value of it.

Even if no other associated real options exist, the above option to defer the investment or the flexibility to decide when to initiate the project after receiving additional information has a positive value. Such flexibility gives an investor the right to wait until more information arrives and make the investment only if the value of the project turns out to exceed the necessary outlay, without imposing any symmetric obligation to invest and incur losses if the opposite scenario occurs. More generally, when other real options are present, a discretionary investment opportunity can be seen as a call option on a collection of the gross project value, $V(t)$, and other real call or put options.

Following Trigeorgis (1996, p. 9-l 3) and Yin and Newman (1999), let's consider a comprehensive example of operation options. Starting from scratch, a producer will invest in timber production with a cost of A4 if the price of timber reaches a certain level. We already talked about the analogy between the option to enter and a call option. If the price of timber rises to yet another higher level, the producer may sell her timber and/or expand her production. The former is simply an exercise of her call option; therefore, it is incorrect to view the harvest (or selling) decision as a put option. The latter to expand the scale of a project by $x\%$ by making an additional investment outlay M_x can be seen as analogous to a call option to acquire $x\%$ of the project's gross value with an exercise price of M_x. Conversely, if the price of timber declines, the producer may decide to cut back the scale of her timber production. Similarly, the option to contract the scale of a project by $y\%$ to save certain expenditures of the magnitude C_y can be viewed as a put option on $y\%$ of the project's gross value with an exercise price of C_y. lfthe price of timber continues to fall such that cash revenues are not adequate to cover the costs of operation in a given year (V(I) < C,), the producer may have to temporarily suspend timber production. In this case, one can think of operation in each year as a call option on that year's cash revenue V(t), the exercise price being the operation cost C_t

On the other hand, if the price of timber bounces back to a higher level later, the suspended timber production may be resumed at a cost ***R.*** Again, this can be seen as a call option to obtain the project's value $V(t)$, with $R + C_t$ being the exercise price. Finally, if the price of timber falls to such a low level as to make reactivation unlikely, the producer may choose to terminate the project in its current use by switching to its future best alternative use or by selling the asset for its salvage value. Switching use or abandoning for salvage value can be treated as a put option on the opportunity's value V(r) -- C,(in its current use), having as an exercise price its value in the best alternative use S.

Implicit in the above illustration is the fact that at the forest level, rotation determination is embedded in the process of timberproduction, which may fluctuate overtimein response to changing market conditions. Of course, this by no means implies that the forest-level framework cannot deal with the rotation determination problem. It should also be said that the producermay have the option to abandon a timberproduction project even during its establishment by "defaulting" on subsequent planned investment cost "installments" if a coming installment outlay exceeds the value from continuing the project. This option to abandon can be viewed as a compound call option on the investment opportunity (with the individual "installments" being the exercise prices).

Looking from a different angle, a timber producer may have other options of strategic significance, such as land lease and acquisition, forest productivity R&D, application of information technology, and asset insurance coverage. In isolation, these actions may appear unattractive. However, these investments can be seen as prerequisites or links in a chain of interrelated projects that shape the future of the investor. The value of these early projects derives not so much from their expected directly measurable cash flows as from the growth opportunities they may induce. Many real options depicted above may be simultaneously present in an investment project; if so, it is proper to view the total investment opportunity as a collection of such real call and put options. However, it should be noted that there may be interactions among these options, which can complicate the assessment immensely. Also, the analogy between real options and call and put options on stock may not be exact, because, unlike financial options, real options are often not traded or owned exclusively in the presence of competitors (Trigeorgis 1996, p. 128).

To sum up, the new framework of forest investment assessment constitutes the evaluation of real investment options at the forest-level. Without a forest-level vehicle, it would be difficult to examine these options. Similarly, without the need to examine these options, it would be less meaningful to adopt such a forest-level vehicle.

Some Technical Issues

A successful implementation of the new framework of forest investment assessment is predicated on our ability to overcome a number of technical problems. Here we discuss three.

Risk Preferences

Forest economists recognize the effect of risk preferences on investment valuation. Some have explicitly considered this effect (e.g., Caulfield 1988, Gong 1998). It turns out that one of the advantages of option valuation is that we are free from being concerned about risk preferences, which greatly reduces the difficulty of evaluating investment projects under uncertainty. Of course, this does not mean that risk preferences do not matter. It only implies that we can obtain the same results in a world of risk aversion as we do in a world of risk neutrality.

Thanks to Cox and Ross (1 976), it is now accepted that any option can be replicated from an equivalent portfolio of traded securities, being independent of risk attitudes and of considerations ofcapital-market equilibrium. Therefore, the risk-neutral valuation, which enables the discounting of expected future payoffs at the risk-free interest rate, has greatly facilitated option pricing. Hull (1997, p. 239-240) further explains that when we move from a risk-neutral world to a risk-averse world, two things happen. The expected growth rate in the stock price changes, and the discount rate that must be used for any payoffs from the derivative changes. It happens that these two effects always offset each other exactly.

Mason and Merton (1 985) argue that, in principle, real options may be valued similar to financial options, even though they are not traded. This is because in capital budgeting, we are interested in determining what the project's cash flows would be worth if they were traded in the market, that is, their contribution to the market value of a tradable firm.

More generally, it has been suggested that any contingent claim on an asset can be priced in a world with systematic risk by replacing its expectation of cash flows with a certainty-equivalent growth rate and then behaves as if the world is risk neutral (Cox, Ingersoll and Ross 1985, Kasanen and Trigeorgis 1994). This is analogous to discounting certainty-equivalent cash flows at the risk-free rate, rather than actually expected cash flows at a risk-adjusted rate.

Price Processes

Although everyone would agree that understanding the dynamics of timber markets is vitally important to forest investment assessment, market analysis has been a weak area of forest economic research. Often, scholars simply assume a price process to behave in a certain way and then move onto deriving the tree-cutting rule. In contrast, few empirical works have been done to examine how stumpage markets actually evolve and how to appropriately characterize them.

In general, random walk and mean-reversion are the two commonly used price processes. A random walk suggests that the public information is quickly incorporated in the current price and the market is efficient, so that arbitrage is impossible (Hull 1997, p. 209-223). In continuous time, a random walk may be represented by a Brownian motion. Further, the geometric Brownian motion is an important special case of the generalized Brownian motion, because it implies that prices are log-normally distributed. The log-normality ensures that prices will never fall below zero but tend to wander far from their starting points. In contrast, if we assume that a price process is normally distributed, we will not be able to rule out the probability that prices can be negative, while most likely they will fluctuate around the mean. Thus, financial analysts prefer to treat stock prices as the following geometric Brownian motions.

$$dP = \alpha P dt + \sigma P dz \qquad (2)$$

where a and σ are a constant drift and standard deviation of prices, and dz is the increment of a standard Wiener process with $E(dz) = 0$ and $E(dz^2) = dt$ (E denotes expectation).

However, one can argue that prices for certain commodities may be related IO the long-run marginal production costs. That is, while in the short run these prices may fluctuate randomly up and down, in the long run they ought to be drawn back towards the marginal costs of production. Thus, one might think that these prices should be properly modeled as mean-reverting processes. The simplest mean-reverting process is known as the Omstein-Uhlenbeck process

$$dP = \eta(\bar{P} - P)dt + \sigma dz \qquad (3)$$

where η is the speed of reversion, and $\bar{P}$ is the "normal" level of P, that is, the level to which P tends to revert (Dixit and Pindyck 1994, p. 74-78). Note that the expected change in P depends on the difference between P and $\bar{P}$. If P is greater (less) than $\bar{P}$, it is more likely to fall (rise) over the next short interval of time. Also, the expected value of P_t co nverges to $\bar{P}$ as t becomes large. Finally, as η approaches zero, P becomes a simple Brownian motion.

Ideally, the choice of a specific price process should be based on empirical testing. Forexample, ifq in Equation (3) is statistically different from zero, then we may model the process as a mean-reversion; otherwise, we may model it as a Brownian motion. Alternatively, we can apply the Dickey-Fuller unit-root test to discern whether a price process is stationary. However, as warned by Dixit and Pindyck (I 994, p. 77–78), even if we have a large number of observations, it may be difficult to statistically distinguish between a random walk and a mean-reverting process. As a result, one must often rely on theoretical considerations and analytic tractability to make the choice.

The Profit Function

Modeling at the forest level can be demanding. In particular, once the uncertainty associated with market price and/or tree growth is incorporated into Equation (1), every endogenous variable-output $F(t)$, inventory I(t), operating input $K(t)$, and land acreage $L(t)$---will change over time. Unfortunately, it would be difficult even if we were to deal with only two control variables in a stochastic analysis. Of course, we can always focus on certain variable(s) [say, $F(t)$], with others assumed to be relatively stable or unchanged. Alternatively, we may simplify our modeling efforts in different ways. One way is that by defining the output after compensating the opportunity cost of stocking volume at t as the net output, or $H(t) = F(t) - i, I(t)$, we can reduce Equation (1) to

$$\pi(t) = P_t H(t) - W_t K(t) - R_t L(t) \qquad (4)$$

Notice that in this case the unit production cost becomes $C(t) = [W, K(t) + R_t L(t)]/H(t)$. If we assume that both P_t an d $H(t)$ follow a geometric Brownian motion, then $V(t) = P, \times H(t)$ also follows a geometric Brownian motion (Dixit and Pindyck 1994, p. 82). Therefore, the analytic complexity can be further reduced. Another idea is to transform Equation (I) or (4) by exploiting the property that these functions are homogeneous of degree I in output and input prices. That is, given equation (4), $\pi(zP_t, z W_t, z R,)$ can be expressed as $z\pi(P_t, W_t, R_t)$. Thus, $\pi(P_t, W_t, R,)$ may be written as, for example, $\pi(P_t/W_t, 1, RJW,)$, so that one state variable is removed from modeling.

Empirical Examples

In this section we present three empirical examples to demonstrate potential applications of forest-level analysis

Table 1. Reservation price determination.

Age	Volume (cord) Pulpwood	Sawtimber	Reservation price	Expected price
			($/cord)	
15	20.40	0.40	91.70	38.58
16	22.84	0.98	85.26	40.26
17	24.84	1.91	80.78	42.58
18	26.40	3.19	77.64	45.37
19	27.54	4.76	75.56	48.40
20	28.32	6.55	74.29	51.51
21	28.79	8.51	73.63	54.60
22	29.03	10.55	73.45	57.54
23	29.06	12.64	73.59	60.35
24	28.95	14.73	73.90	62.97
25	2X.71	16.79	74.29	65.40
26	28.38	18.78	74.63	67.64
27	27.98	20.7 1	74.69	69.72
28	27.52	22.54	74.19	71.63
29	27.02	24.28	72.07	73.40

and the options valuation approach. We hope that they will illustrate the usefulness of adopting the new framework.

Harvest Timing

Since a stand of trees is a special case of a forest, it is straightforward to determine the optimal harvest policy at the forest level. Yin (199'7) has already done so for a deterministic case.Herewederive the solution for a stochastic case. Recall that the thrust of rotation determination is to compare the net value of a stand of trees in the current period with the expected net present value of the stand in the next period. If the former is no less than the latter, the stand is harvested; otherwise, the harvest is postponed. Based on the profit function defined in (I), the decision is to cut the trees if $\pi_t \geq \mathscr{E}[\pi_{t+1}]/(1+i)]$, or wait for one more period if $\pi_t < 8\ [\pi_{t+1}]/(1+i)]$ where $\mathscr{E}[.]$ represents expectation, and i is the discount rate.

The above optimal decision rule is then implemented in a way similar to that of Lohmander (1987), Brazee and Mendelsohn (I 988), and Haight (1990). Namely, by introducing the distribution of the stumpage price, we first derive the expected profit of a timber sale in year t given a reservation price, P_{rt} ; then, we obtain the present value of all future expected profits starting from year 0; and finally, by reducing comparing profits in two neighboring periods to comparing prices, we formulate the reservation price rule. This dynamic programming problem is solved recursively. That is, once a maximum harvest age T is specified, its expected price $\mathscr{E}[P_T]$ can be calculated to derive P_{rT-1}. Going back for another period, P_{rT-2} is similarly determined. In the end, a reservation price schedule is obtained. Accordingly, we can find the probability at which the trees are cut in a certain period.

Our example features a slash pine plantation, the S case in Yin et al. (1998). The growth process (Table 1) includes pulpwood and sawtimber production. Cost parameters are also based on Yin et al. (1998) and include annual land rental cost ($5 1.89/ha), operating cost ($9.60/ha), and discount rate (6%). In addition, quarterly prices for pulpwood and sawtimber in the coastal area of Georgia are taken from Timber Mart-South (1998). The mean value and standard deviation are, respectively, $15.39/m^3 and $1.54/m^{3}f or pulpwood, and $47.22/m^3 and $4.72/m^3 for sawtimber. For simplicity, we further assume that the price processes are independently normally distributed.

As shown in Figure 2, early on the trees are too young to be cut; thus, the reservation price is high. But as trees approach the static Faustmann rotation age (close to 26 yr), the reservation price reaches its lower bound and then turns upwards a bit. Therefore, there is a greater likelihood of harvest in this range, with the mean rotation age being 26.2 yr. Notably, the presence ofmultiple products and the price differential between them cause our reported reservation price to represent an average between pulpwood and sawtimber reservation prices. We see that determining the optimal harvest policy at the forest level can simplify the analytic exercise because land rental and capital costs of timber production are explicitly incorporated. The forest level analysis also provides a platform for unifying harvest timing with other operation decisions.

Entry Decision

Here we compare the optimal entry prices in the deterministic and stochastic world. We will show that the stochastic entry price is much higher than the deterministic one; that is, in a stochastic world, an investor should wait for a higher market price to commit to a project. Dixit and Pindyck (1994, p. 140-142) have shown that, assuming profit function (I) and price process (2), the differential equation for the value of the project is

$$\frac{1}{2}\sigma^2 P^2 V''(P) + \alpha P V'(P) - iV(P) + \pi(P) = 0 \qquad (5)$$

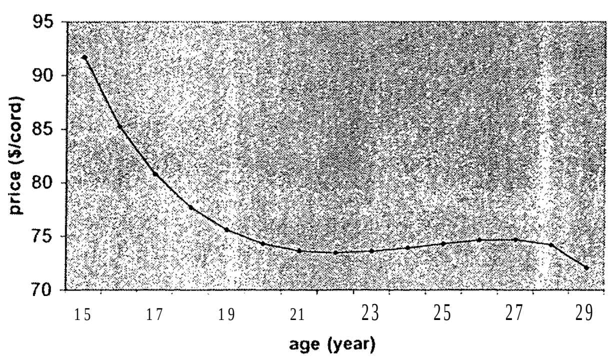

Figure 2. The reservation price curve.

Its general solution is

$$V(P) = D\,P^{\beta_2} - P/\delta - C/i,$$

where

$$D = \frac{C^{1-\beta_2}}{\beta_1 - \beta_2}\left(\frac{\beta_1}{i} - \frac{\beta_1 - 1}{\delta}\right)$$

with

$$\beta_1 = \frac{1}{2} - \alpha/\sigma^2 + \sqrt{[\alpha/\sigma^2 - \frac{1}{2}]^2 + 2i/\sigma^2},$$

$$\beta_2 = \frac{1}{2} - \alpha/\sigma^2 - \sqrt{[\alpha/\sigma^2 - \frac{1}{2}]^2 + 2i/\sigma^2}, \quad \text{and}$$

$$\delta = i - \alpha.$$

Similarly, the value of the option to invest in the project is $H(P) = A\,P^{\beta_1}$, where A is a constant.

Using the value-matching and smooth-pasting conditions at the optimal entry price P^*, we have

$$A[P^*]^{\beta_1} = D[P^*]^{\beta_2} + P^*/\delta - C/i - M \tag{6}$$

$$(\beta_1 A[P^*]^{\beta_1 - 1} = \beta_2 D[P^*]^{\beta_2 - 1} + 1/\delta \tag{7}$$

Substituting D into the above two equations and eliminating A, we obtain

$$(\beta_1 - \beta_2)D[P^*]^{\beta_2} + (\beta_1 - 1)P^*/\delta - \beta_1(C/i + M) = 0 \tag{8}$$

Equation (8) gives the optimal entry price P^*, which can be solved numerically.

Our numerical case features an old field loblolly pine plantation in Georgia, with a site index 55. The number of trees planted is 1977/ha.[3] Products per hectare include 220.0 m^3 of pulpwood and 28.6 m^3 of chip-n-saw at a rotation age of 28 yr. Prices are \$10.37/m^3 for pulpwood and \$25.93/m^3 for chip-n-saw. Therefore the weighted average price of \$12.17/m^3, with an annual growth rate of a = 0.01 and a variance of σ^2 = 0.076. Accordingly, the annual operating cost per hectare is \$558.46, the land rental cost is \$498.16, the capital cost is \$1622.90, and the interest rate (i) is 4%. Thus, the unit variable cost is \$10.79/m^3, and the investment cost for establishing such a forest is \$110.62/m^3.

With this information, the calculated option value, $H(P)$, and project value, $V(P)$, are plotted in Figure 3. It is found that P^* = \$27.45/m^3, indicating that, given the underlying market parameters, an investor would consider investing in timber production only if the price reaches \$27.45/m^3. In contrast, if the price volatility were ignored, the static entry price, P', would be just \$15.21/m^3 (the long-run average cost, or the sum of the variable cost and interest on the investment sunk costs. Also notice that, as σ increases (i.e., stumpage price becomes more volatile), the value of the investment option, $H(P)$, becomes higher, causing an increase in P^* and thus a decrease in investment. That is exactly why it is important to wait for new information before entry in an uncertain environment.

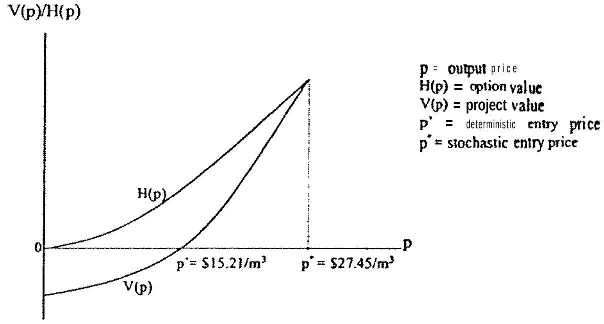

Figure 3. Determining when to enter.

Land Acquisition

A timberland investment management company (TIMCO) has recently acquired a tract of softwood timberland in the U.S. South. The price was \$1482.63/ha. According to specifications of the commingled fund, the TIMCO shall sell the timberland in 10 yr to yield an annual (nominal) rate of return of 8% for its clients. The company expects that in the next 10 yr, the timber will grow at an annual rate of 5%, and the timber price will appreciate at an annual rate of 4%. This implies that after delivering the promised rate of return to its clients, the remaining 1% return can just cover the company's annual management fee (100 basis points per year). As a result, there will be no performance incentive available (which constitutes about 10% of the surplus revenue at the end of the contract). The TIMCO was not very positive about the acquisition at the beginning.

However, its senior financial analyst argued that this would not be as bad a deal as the above static NPV analysis suggested. He pointed out that the remaining 1% annual rate of return results from an ignorance of the market volatility. With a fluctuating regional timber market, a well-timed decision of liquidation can give rise to a higher rate of return. Then he showed that if the volatility of the regional timber price is about 25% annually and the risk-free interest rate is 5.2%, as commonly used, the NPV of the timberland opportunity should be \$1776.07/ha because of the option value of \$293.44/ha associated with the investment.

The analyst's calculation was based on the following model for an American call option :

$$\Omega(S, \tau, E) = SN(d_1) - Ee^{-r\tau}N(d_2) \tag{9}$$

where $\Omega(S, \tau, E)$ is the value of the call option, S is the underlying asset price at current time, τ is the time to the expiration of the option, E is the exercise price of the option, r is the risk-free interest rate, d_1 and d_2 are defined as

[3] See Yin and Newman (1999) for details of this case.

$$d_1 = \frac{\ln(S/E + (r + 1/2\sigma^2)\tau}{\sigma\sqrt{\tau}}$$

and

$$d_2 = d_1 - \sigma\sqrt{\tau},$$

σ is the asset price volatility, and $N(.)$ is the cumulative standard normal distribution function (Black and Shoals 1973). Given that S = \$1482.63/ha, τ = IO, r = 5.2%, E = \$3509.93/ha (the expected asset value in IO yr), and σ = 25%, he found that Ω = \$293.44/ha.

With a different asset valuation, he further explained, the TlMCO should expect to sell the timberland at around \$3995.70/ha in 10 yr, which results from the asset base value (\$1482.63) being compounded at the expected annual return of 9% and the associated option value (\$293.44) being compounded at the risk-free rate of 5.2%. This would translate into an effective annual return of 10.4% to the investment ($[3995.70/1482.63]^{1/10}$), making both the TlMCO and its clients happier.

As noted earlier, if asset acquisition is the act to purchase a real call option, asset disposition can be viewed as the act to exercise the call. To gauge what is the gain from harvesting timing, therefore, all we need is to evaluate the call option like what we have just done. This means that now we can directly obtain the benefit of harvest timing. In contrast, working at the stand level, this is calculated as the residual of the expected NPV under uncertainty over the static Faustmann NPV.

Closing Remarks

We have proposed a new framework for forest investment assessment under market uncertainty-the evaluation of real investment options at the forest level. First, we articulated the necessity for forest-level analysis and the multiplicity of forestry investment options. Then we discussed some technical issues and presented three examples as to when to commit an investment, how to evaluate a land acquisition decision, and what time to cut a timber stand. We hope that, as these examples demonstrated, adopting this new framework can be beneficial.

Certainly, our new framework will make it possible for us to evaluate many forest operation opportunities. And given the tremendous structural shifts of timber markets and the increased interest in intensive forest management, the need to assess these investment opportunities are greater than ever before. Furthermore, under market uncertainty, risk management-adjusting the actual level of risk exposure to the desired level by means of asset instrumentation and portfolio diversification-is important to business success. In this regard, our proposed framework will introduce us to recent advancements in financial economics, making new ideas and tools available to forest economists. We expect that with expanded analytic capabilities, forest economists will be able to play a more active role in capital budgeting and strategic planning related to forestry.

Also, we need an enhanced knowledge base to explain a whole host of questions. For instance, why do NIPF landowners use management intensity and rotation regimes different from those of industrial landowners? Why have forest products firms invested in forest productivity and resource management R&D while they are downsizing their land holdings? Why have institutional timberland investments performed better than industrial and NIPF landowners? We believe that analyses based on the new framework will ultimately give rise to more thorough understandings of these and other questions and yield better interpretations of the behavior of landowners.

In short, combining forest-level analysis with the options valuation approach constitutes a promising opportunity to expand forestry investment assessment. To take advantage of the opportunity, however, forest economists need to make concerted efforts to tackle some major technical issues and generate more case studies. Finally, it should be emphasized that proposing this new perspective at the forest level by no means implies the abandonment of the stand-level Faustmann framework. Rather, what we believe is that various forest issues should be addressed with appropriate approaches. The stand-level Faustmann framework is appropriate for certain issues, but it may not be appropriate for others. In that case, we need to adopt alternative frameworks, including the one we have suggested in this article.

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